CHANGING WHAT'S POSSIBLE

GridCloud: Managing the Smart Grid with Highly Assured Cloud Computing

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Cornell University

Washington State University

World Class. Face to Face.

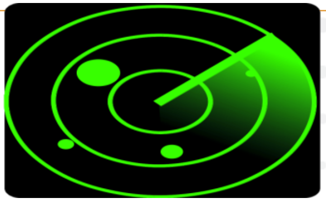
Project Objectives

- Goal: Demonstrate a viable cloud stack for smart grids
  - Meet real-time, scalability, robustness requirements
  - Prototype a working open-source system
  - Demonstrate a real application at scale
- Challenge: Commercial clouds provide few *guarantees*!
- Metrics: Demo monitoring real-time properties of 15K bus network model with injected failure scenarios on EC2

Team Responsibilities

- Cornell University [Birman, Van Renesse, Bindel]
  - Leverage DARPA-funded Isis2 system + IronStack high assurance networking in basic platform. Create monitoring and self-management framework (DMake) and a secure and unbreakable connection technology (TCP-R+SSL/TLS)
- Washington State University [Hauser, Bakken, Bose]
  - Adapt DOE-funded GridStat platform to run on GridCloud and leverage its scalable fault tolerance
  - Show that in this configuration, Grid Stat can scale to meet real-time state estimation targets

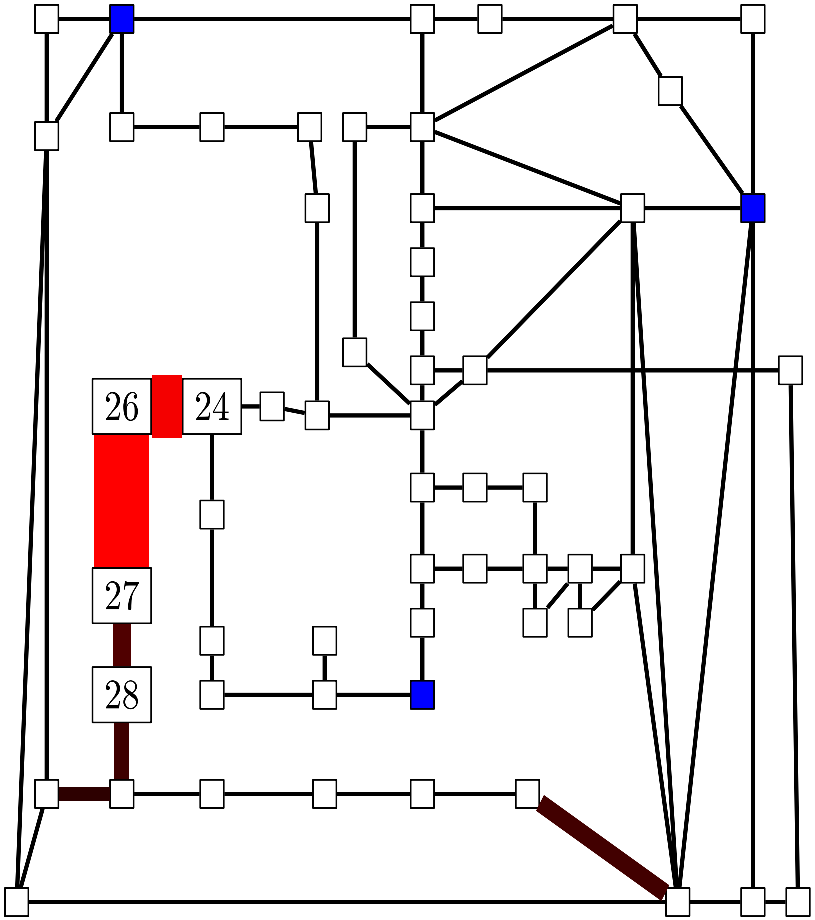
Smart Grid Radar



- Goal: PMUs monitor “weather” on grids
  - Track (and mitigate) bad transients
  - Use harmless transients to refine grid models
    - Are line parameters changing?
    - How do transients pass through neighbors?
    - What’s the actual topology?

- Want to fuse all available info in diagnoses
- Want information at PMU speeds for fast response

FLiER: Contingency Fingerprints



- Topology changes leave "fingerprints"
- See line failures, breaker changes
- Estimate by linearization about recent state
- Score contingencies by fingerprint match
- Filter possibilities via angle to subspace

- Accurate:
  - PMU everywhere: Almost all right
  - Sparse PMUs: Usually right, generally "close" if wrong
- Fast diagnosis
  - Ex: Polish network with ~3000 lines
  - 100 PMUs placed randomly
  - Fail random line and time
  - Less than ten possibilities pass filter
  - Typical run: 0.25-0.5 seconds (unoptimized Python implementation)

The Next Six Months

- Detailed performance measurements on EC2
- Completion of ISO NE pilot project
  - PMU source, PMU metadata repository, data relay
  - WSU PMU-based state estimator
  - Output visualization
- Dynamic event fingerprinting

Platform Building

GridCloud Core Technologies

Highly Assured Cloud Computing Technology

sponsored by the Department of Energy ARPA-E program

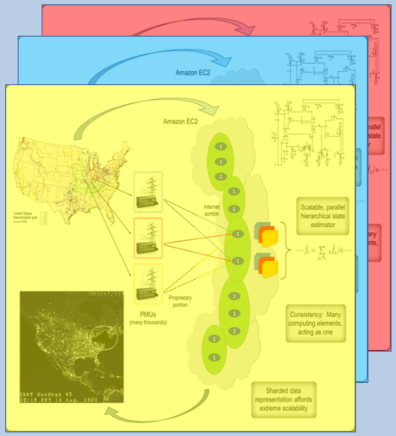
Cornell University

Why Clouds?

- Cost effective: pay only for resources you are using, amortize infrastructure over many users
- Geographic scale: multiple data centers at widely separated locations gives physical reliability
- Scalable capacity: potential to do real-time tracking of PMU data at national scale

What Makes it Hard?

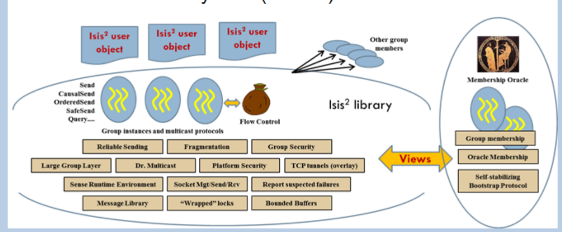
- Today's cloud is inadequately secure and has poor real-time guarantees
- At scale with many moving parts, transient and permanent faults are common, and rare events occur surprisingly often
- We need a computing model that matches the reality: multiple operators
- We need to find scalable ways to compute state estimates rapidly and robustly
- Even if power industry runs the cloud, demands new trust and auditing approaches



Application Layer

Real-Time State Estimation enabling a wide range of new operator-oriented functionality and the potential for direct control of sensitive tasks

Isis Library: Our (hidden) secret sauce



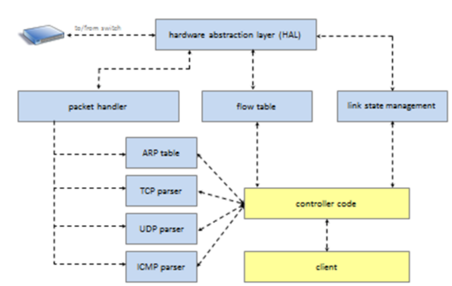
Performance targets?

- 15,000 or more PMUs or other sensor devices monitored at 30Hz
- Nationwide physical scale
- 30 State estimates per second with 250ms delay
- Delays 10x smaller in smaller regional setups
- Instant and automated recovery from faults. Geographic replication to handle major outages.

Status?

- GridCloud is working! Demos at steadily increasing scale (but using simulated data, and Amazon EC2).

IronStack software architecture



Three key techniques

- Redundancy / Replication
- Consistent monitoring and management
- Software defined network with real-time guarantees

Tools

- **Isis2:** A DARPA funded Cornell-developed toolkit for building highly assured cloud computing solutions. Aims at programmers.
- **DMake:** Based on Isis2, monitors and manages a large, complex system. Aims at a higher level system operator.
- **IronStack:** A new networking package that transforms private networks into highly secure, highly assured real-time network solutions

Future:

- **Powerful operator-oriented visualization and collaboration tools**
- Think of a table-sized tablet with a wide range of "smart" computational elements you can touch/drag/drop

Building on the Platform

- Plumbing is a pre-requisite
  - Isis2 + DMake + IronStack + GridStat + Sprinkler + …
- But plumbing is not the purpose!
  - GridCloud currently supports PMU-based state estimator
  - Full state estimates (5/s) on 15K PMU test network (WECC model x3)
  - Preliminary development of other “fingerprint” apps

Technology-to-Market

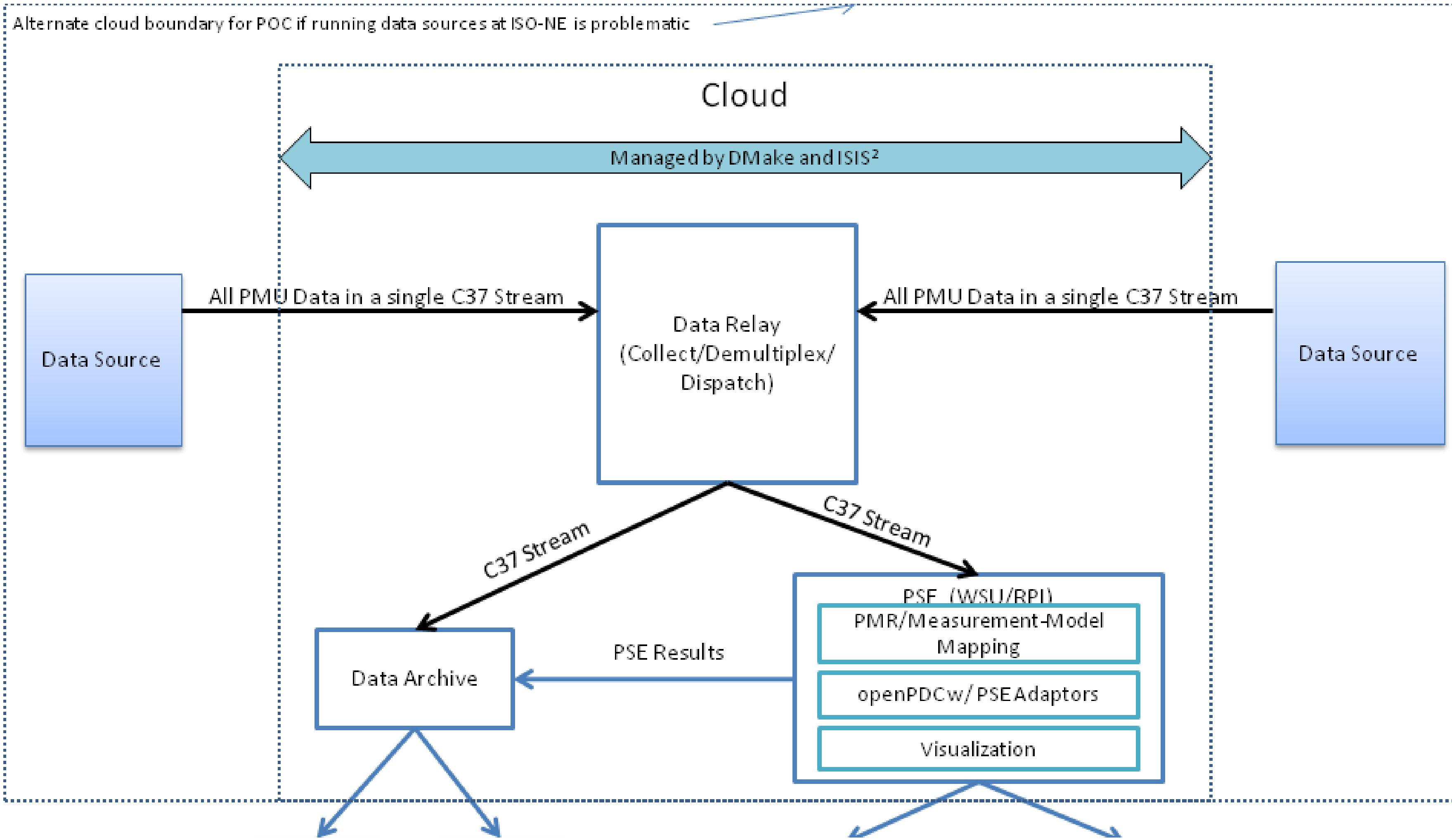
- Goal: *Open* cloud *platform* for smart grid applications
- Relevant metrics
  - Does industry view the work as credible?
  - Will the approach be adopted by vendors?
- Pilot with ISO-NE is a first step to industry adoption
  - We are also engaging with NYPA and ISO NY
- Bakken pursuing other leads (RTE France, EPRI, BPA; KTH, TU Darmstadt; many other panels and discussions)

- Also a commercial path for some software
  - WSU spun off a company to market GridStat
  - IronStack is in early pre-commercialization phase

ISO-NE Pilot Project

- Vision (Eugene): Common platform for ISO and utilities to
  - Share real-time and historical PMU data
  - Share results of applications that use that data
- Pilot experiment: GridCloud tech + ISO-NE PMU data
  - Study cloud feasibility: issues raised, costs, etc
  - Collect PMU data in cloud using GridCloud
  - Run hierarchical linear state estimator in cloud
- System will demonstrate
  - Multiple uses of PMU data
  - Real-time results from a cloud app delivered to utility
  - Sufficiently small latency in measurement delivery
  - Manageability of cloud components
  - Integration of PMU measurement data from multiple sources

ISO-NE Demo Block Diagram



Post ARPA-E Goals

- Growing collaboration from pilot with ISO-NE
- Goal: Federated system for monitoring and simulation
  - Provide path to local adoption, broad vendor ecosystem
  - Plumbing: coordinate commercial cloud, local clusters
  - Monitoring: state estimation, fingerprints, etc
  - Simulation: iteratively reconcile sims across areas
- Funding sources
  - Expect DARPA to continue investment in core tech
  - Proposal out to NSF
  - DOE more suitable for smart-grid specific activities
  - Possible local interactions with NYSERDA

Conclusions

"The future is already here – it's just not very evenly distributed"
- William Gibson

"Easy things should be easy, and hard things should be possible"
- Larry Wall

- Distributed cloud-hosted platforms make sense
  - Cloud platforms are ubiquitous in other areas
  - Even the current grid is a distributed system
- Crucial to invest in engineering these platforms
  - Commercial grids fit Google / Facebook, not grid
  - Going beyond "best effort" is hard
  - Platform work enables novel analysis tools